JC08 Rec'd PCT/PTO 16 FEB 2001

FORM PTO-1390 (REV. 5-93) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTORNEY'S DOCKET NUMBER **10191/1711**
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371	U.S. APPLICATION NO. (If known, see 37 CFR 1.5) 09/763138

INTERNATIONAL APPLICATION NO	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED:
PCT/DE00/01906	**(16.06.00) 16 June 2000**	**(18.06.99) 18 June 1999**

TITLE OF INVENTION

DEVICE AND METHOD FOR HIGH-RATE ETCHING A SUBSTRATE USING A PLASMA ETCHING SYSTEM AND DEVICE AND METHOD FOR IGNITING A PLASMA AND ADJUSTING UPWARD OR PULSING THE PLASMA POWER

APPLICANT(S) FOR DO/EO/US

BECKER, Volker; LAERMER, Franz; SCHILP, Andrea; and BECK, Thomas

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This express request to begin national examination procedures (35 U.S.C. 371(f)) immediately rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☐ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   - b. ☒ has been transmitted by the International Bureau.
   - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US)
6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   - b. ☐ have been transmitted by the International Bureau.
   - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   - d. ☒ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)) . (Unsigned)
10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern other document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A **FIRST** preliminary amendment.
    ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
14. ☐ A substitute specification.
15. ☐ A change of power of attorney and/or address letter
16. ☒ Other items or information: International Search Report; and PCT/RO/101.

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NY01 344907 v 1

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U.S. APPLICATION NO. (if known, see 37 C.F.R.1.5) 09/763138	INTERNATIONAL APPLICATION NO PCT/DE00/01906	ATTORNEY'S DOCKET NUMBER 10191/1711

17. ☒ The following fees are submitted:

Basic National Fee (37 CFR 1.492(a)(1)-(5)):

Search Report has been prepared by the EUROPEAN PATENT OFFICE or JPO $860.00

International preliminary examination fee paid to USPTO (37 CFR 1.482) $690.00

No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) $710.00

Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1 445(a)(2)) paid to USPTO $1000.00

International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) $100.00

				CALCULATIONS	PTO USE ONLY
ENTER APPROPRIATE BASIC FEE AMOUNT =				$ 860.00	
Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).				$	
Claims	Number Filed	Number Extra	Rate		
Total Claims	17 - 20 =	10	X $18.00	$ 0	
Independent Claims	1 - 3 =	0	X $80.00	$ 0	
Multiple dependent claim(s) (if applicable)			+ $270.00	$ 0	
TOTAL OF ABOVE CALCULATIONS =				$860.00	
Reduction by ½ for filing by small entity, if applicable. Verified Small Entity statement must also be filed. (Note 37 CFR 1.9, 1.27, 1.28).				$	
SUBTOTAL =				$860.00	
Processing fee of $130.00 for furnishing the English translation later the ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)) +				$	
TOTAL NATIONAL FEE =				$860.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). $40.00 per property +				$	
TOTAL FEES ENCLOSED =				$860.00	
				Amount to be: refunded	$
				charged	$

a. ☐ A check in the amount of $__________ to cover the above fees is enclosed.

b. ☒ Please charge my Deposit Account No. 11-0600 in the amount of **$860.00** to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 11-0600. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1 495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

Richard L. Mayer
By: Mary C. Werner Reg. No. 30,333
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2/16/01
DATE

NY01 344907 v 1

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Inventor(s)	:	Volker BECKER et al.
Serial No.	:	To Be Assigned
Filed	:	Herewith
For	:	**DEVICE AND METHOD FOR HIGH-RATE ETCHING A SUBSTRATE USING A PLASMA ETCHING SYSTEM AND DEVICE AND METHOD FOR IGNITING A PLASMA AND ADJUSTING UPWARD OR PULSING THE PLASMA POWER**
Examiner	:	To Be Assigned
Art Unit	:	To Be Assigned

Assistant Commissioner for Patents
Washington, D.C. 20231

PRELIMINARY AMENDMENT

SIR:

Kindly amend the above-identified application before examination as set forth below.

IN THE SPECIFICATION:

On page 1, before line 5, insert: --FIELD OF THE INVENTION-- .

On page 1, line 13, delete "Related Art" and insert: --DESCRIPTION OF RELATED ART--.

On page 3, line 13, change "German Patent 41 42 045 C1" to --German Patent 42 41 045 C1--.

On page 4, line 19, insert: --SUMMARY OF THE INVENTION-- .

On page 4, line 28, delete "Advantages of the Invention".

On page 7, line 36, delete "Drawing" and insert:
--<u>BRIEF DESCRIPTION OF THE DRAWINGS</u>-- .

Page 8, line 11, delete "Exemplary embodiments" and insert:
--<u>DETAILED DESCRIPTION OF THE INVENTION</u>--.

<u>IN THE CLAIMS</u>:

On page 17, line 1, delete "Patent Claims" and insert:
--<u>WHAT IS CLAIMED IS</u>:--.

Cancel claims 1-17, without prejudice.

Add the following new claims 18-34:

--18. (New) A device for etching a patterned silicon body substrate (10) with a plasma (14), comprising: a plasma source (13) for generating a high-frequency electromagnetic alternating field power to be applied to the plasma source with assistance of a high-frequency generator (17); a reactor (15) for generating the plasma (14) from reactive particles through the action of the high-frequency electromagnetic alternating field upon a reactive gas or a reactive gas mixture; and a first means for producing a periodical change in the high-frequency power applied to the plasma source (13).

19. (New) The device according to Claim 18, wherein the first means is: a component for controlling the power of the high-frequency generator in which component a digital ramp generator is programmed via a software, or a component (18) for controlling the power of the high-frequency generator which component has an analog ramp generator (19).

20. (New) The device according to Claim 19, wherein the analog ramp generator (19) has an RC circuit (23, 24, 25) which is provided with at least one diode.

21. (New) The device according to Claim 18, further comprising a second means which, during the periodical change in the high-frequency power applied to the plasma source (13), at least temporarily adapts the output impedance of the high-frequency

generator (17) to the prevailing impedance of the plasma source (13) which changes as a function of the high-frequency power.

22. (New) The device according to Claim 21, wherein the adaptation of the output impedance is carried out continuously or stepwise and is automated and wherein the applied high-frequency power lies between 400 W and 5000 W.

23. (New) The device according to Claim 21, wherein the second means is an impedance transformer (16).

24. (New) A method for anisotropically etching a substrate (10) using the device according to Claim 18, comprising the steps of carrying out the anisotropic etching process in separate etching and polymerization steps alternatingly following each other, and applying a polymer to lateral patterns defined by an etching mask during the polymerization steps, the polymer being removed again in each case during the subsequent etching steps, wherein, during the etching steps, at least temporarily, and in each case higher high-frequency power is applied to the plasma source (13) than during the deposition steps.

25. (New) The method according to Claim 24, wherein during the etching steps, at least temporarily, a high-frequency power of 800 watts to 5000 watts, in particular, of 2000 watts to 4000 watts is applied to the plasma source (13), and during the deposition steps, at least temporarily, a high-frequency power of 400 watts to 1500 watts, in particular, of 500 to 1000 watts is applied to the plasma source.

26. (New) The method according to Claim 24, wherein the increase in the high-frequency power during the change from the deposition steps to the etching steps or the decrease in the high-frequency power during the change from the etching steps to the deposition steps are carried out stepwise or continuously.

27. (New) The method according to Claim 26, wherein at least the increase in the high-frequency power is carried out in such a manner that during this time, at least temporarily, the impedance of the high-frequency generator (17) is adapted to the plasma impedance at least approximately in a, in particular, continuous or stepwise and automated manner via the second means, in particular, via the impedance transformer (16).

28. (New) The method according to Claim 26, wherein the duration of the increase in the high-frequency power during the change from a deposition step to an etching step is 0.2 sec to 5 sec, in particular, 0.5 sec to 3 sec and/or that the duration of the decrease in the high-frequency power during the change from an etching step to a deposition step is 0 sec to 2 sec, in particular, 0 sec to 0.5 sec.

29. (New) A device for igniting a plasma (14) and for adjusting upward or pulsing a plasma power, comprising: an inductive plasma source (13), for generating a high-frequency electromagnetic alternating field, it being possible for a high-frequency power to be applied to the plasma source with the assistance of a high-frequency generator (17); a reactor (15) for generating the plasma (14) from reactive particles through the action of the high-frequency electromagnetic alternating field upon a reactive gas or a reactive gas mixture; and a means which permits adjustment of a continuous or stepwise increase in the high-frequency power applied to the plasma source (13), starting from a starting value, to a target value.

30. (New) The device according to Claim 29, wherein the means is: a component for controlling the power of the high-frequency generator (17) in which component a digital ramp generator is programmed via a software, or a component (18) for controlling the power of the high-frequency generator (17) which component has an analog ramp generator (19).

31. (New) The device according to Claim 29, further comprising an impedance transformer (16) which, during the increase in the high-frequency power, at least temporarily, adapts the output impedance of the high-frequency generator (17) to the prevailing impedance of the plasma source (13) in a an, in particular continuous or stepwise and automated manner, the impedance of the plasma source changing as a function of the high-frequency power.

32. (New) A method for igniting a plasma (14) and for adjusting upward a plasma power using the device according to Claim 29, wherein the continuous or stepwise increase in the high-frequency power from the starting value to the target value is accompanied by an at least temporary impedance adaptation of the high-frequency generator (17) to the

prevailing plasma impedance via the second means, in particular, via the impedance transformer (16).

33. (New) The method according to Claim 32, wherein the starting value is 0 to 400 watts and the target value is 800 watts to 5000 watts, and wherein the increase of the starting value to the target value is carried out over a period of 0.2 sec to 5 sec, in particular, 0.5 to 2 sec.

34. (New) The method according to Claim 32, wherein the plasma (14) is ignited and adjusted upward in a time-pulsed manner.--

Remarks

This Preliminary Amendment cancels, without prejudice, original claims 1-17 in the underlying PCT Application No. PCT/DE00/01906. These claims have been rewritten as new claims 18-34 so as to conform the claims to U.S. Patent and Trademark Office rules, and they do not add new matter to the application.

The above amendments to the specification and abstract conform the specification and abstract to U.S. Patent and Trademark Office rules and incorporate any changes made in the underlying PCT application during the international stage. These amendments do not introduce any new matter into the application.

The underlying PCT Application No. PCT/DE00/01906 includes an International Search Report, dated December 18, 2000. The Search Report includes a list of documents that were uncovered in the search for the underlying PCT Application. A copy of the Search Report is included herewith.

Applicants assert that the subject matter of the present application is new, non-obvious, and useful. Prompt consideration and allowance of the application are respectfully requested.

Respectfully submitted,

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Dated: 2/16/01

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[10191/1711]

DEVICE AND METHOD FOR HIGH-RATE ETCHING A SUBSTRATE USING A PLASMA ETCHING SYSTEM AND DEVICE AND METHOD FOR IGNITING A PLASMA AND ADJUSTING UPWARD OR PULSING THE PLASMA POWER

The present invention relates to a device and a method for high-rate etching a substrate, in particular, in an anisotropic manner, using a plasma etching system, it being possible to achieve periodically varying plasma powers of up to 5000 watts as well as to a device and a method for igniting a plasma and to adjusting upward or pulsing the plasma power according to the species defined in the independent claims.

Related Art

German Patent 42 41 045 C1 describes a method for anisotropically etching silicon using high etching rates and high mask selectivity, a high-density plasma source having preferably inductive high-frequency excitation being used for liberating fluor radicals from a fluor-delivering etching gas and $(CF_2)_x$-radicals from a passivating gas delivering Teflon-forming monomers. In the process, etching gas and passivating gas are used alternatingly, a side wall polymer film being built up on the side walls of already etched patterns during the passivation steps or polymerization steps, the side wall polymer film, during the per se isotropic etching steps, each time being partially removed again with the assistance of ions and, at the same time, the silicon pattern ground being etched by fluor radicals. This process requires a high-density plasma source which also generates a relatively high density of ions (10^{10}-10^{11} cm^{-3}) of low energy.

An increase in the etching rate, which is required for many applications, is generally to be expected when the high-frequency power coupled into the plasma is increased.

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In methods as described in German Patent 42 41 045 C1, however, this is surprisingly not the case. Instead, it is observed that the etching rate in silicon increases only slightly in response to increasing the power of the plasma source while, at the same time, unwanted profile deviations, in particular, in the upper third of the produced trenches, greatly increase, resulting in profile indentations or undercuts of the mask edge.

These effects, on one hand, originate from unwanted capacitive interferences from regions of the inductive plasma source, which carry very high high-frequency voltages. When working with higher powers and voltages, these unwanted interference effects are naturally higher as well.

In so far as the plasma source itself is affected, the mentioned effects can be rectified at least to a great extent by advanced feed concepts of the plasma source and, for example, by using a special aperture as is described in German Patent 197 34 278 C1. However, those profile deteriorations which are due to the process and therefore have to be tackled from the process side remain.

While in simple plasma patterning processes, an increase in the plasma power, because of the resulting increased production of ions and etching species, gives rise to the desired increase in the etching rate, in the case of the method according to German Patent 42 41 045 C1, the deposition steps must also be taken into account in addition to the etching steps. In this context, an increase in the plasma power during the etching steps not results in the desired increased production of etching species and ions but also changes the deposition steps in a characteristic manner.

A very important aspect of German Patent 42 41 045 C1 is the side wall film transport mechanism which, during the per se isotropic etching steps, assures that the side wall protective

film is also moved into the depth of the trench during further etching and that it can provide local edge protection already there. However, during the deposition or polymerization steps themselves, such a transport mechanism is only desired within certain limits. Thus, the intention is, in particular, to prevent that excessive side wall polymer is driven down into the trenches already during the deposition cycles and that it is then lacking above, i.e., the side wall film gets too thin there.

If the plasma power is increased during the etching and deposition steps, for example, in the case of a process according to German Patent 41 42 045 C1, an increased polymer transport from the side wall into the depth of the trenches takes place, per se unintentionally, also during the deposition steps in competition to the coating of the side walls since, above a certain plasma power, the deposition rate can no longer be substantially increased but, instead, ions are increasingly produced which impinge on the substrate to be etched.

Due to the plasma potential which lies somewhat above the substrate potential even without an additionally applied substrate electrode voltage, this increasing ion flux toward the substrate results in that an increasing part of the deposited film material is pushed into the depth of the trenches and to the etching ground already during the deposition steps. In particular, the plasma has a plasma potential of several Volts up to several 10 Volts with respect to grounded surfaces and, consequently, also with respect to a substrate on the substrate electrode, which is tantamount to a corresponding ion acceleration toward the wafer. Therefore, an increased ion density also signifies an increased ion action upon the substrate surface and, in particular, upon the trench side walls although, explicitly, no ion acceleration voltage is applied to the substrates.

As a result of the explained polymer removal and carrying over into the depth of the trenches already during the deposition steps in the case of very high plasma powers, the polymer material needed for the side wall protection in the subsequent etching steps is finally lacking in the upper parts of the etched trenches when working with high plasma powers, which manifests itself in the mentioned profile deviations more or less in the upper third of the trench profile. At the same time, the polymer material transported to the etching ground in excess also disturbs the etch removal during the subsequent etching steps and, on the whole, leads to the observed saturation of the etching rate in spite of the further power increase in the source. A further effect in this connection is the "hardening" of the deposited polymer material when working with very high power densities, i.e., an increased carbon content in polymers compacted in this manner, which makes the subsequent polymer removal more difficult and, consequently, reduces the etching rates.

Therefore, it is an object of the present invention to overcome a saturation of the etching rate in spite of a higher high-frequency power provided by the plasma source, thus drastically increasing the etching rate. A further object of the present invention is to enable the ignition and the coupling in of very high high-frequency powers into a, in particular, inductive plasma source in a stable manner.

Advantages of the Invention

The devices according to the present invention and the methods according to the present invention having the characterizing features of the independent claims have the advantage over the background art that they allow the high-frequency power applied to a plasma source to be periodically changed so that, for example, alternating deposition or polymerization and etching steps can be carried out very advantageously using high-frequency powers of different magnitude. In this context,

a higher high-frequency power is in each instance very advantageously applied to the plasma source during the etching steps than during the deposition steps.

Moreover, using the device for etching according to the present invention and the method for anisotropically etching a substrate according to the present invention, considerably higher etching rates can be achieved than with known etching methods and etching devices. In this context, the difficulty existing in known methods heretofore that, in spite of a continuous increase in the plasma power, a saturation of the etching rate occurs in anisotropic etching methods where deposition steps and etching steps are used alternatingly.

Furthermore, it is very advantageous that the device according to the present invention and the method for igniting and adjusting upward a plasma carried out therewith, for the first time, allow very high high-frequency powers to be coupled into a, in particular, inductive plasma source in a stable manner.

Advantageous embodiments of the present invention are derived from the measures specified in the subclaims.

Thus, the method according to the present invention allows the method according to German Patent 42 41 045 C1 to be considerably improved in a very advantageous manner by applying a low plasma power during the deposition steps and by applying a very high plasma power during the etching steps, extremely high etching rates being attained, for example, in silicon while retaining the advantages known from German Patent 42 41 045 C1. In the etching method according to the present invention, in particular, the deposition steps very advantageously remain nearly unchanged. Moreover, the etching steps are advantageously carried out using very high plasma powers of up to 5000 watts at preferably increased SF_6/O_2 flow and preferably increased process pressure.

Besides, the uniformity of the etching process is significantly improved by switching back the high-frequency power, according to the present invention, during the polymerization steps so that the substrate center and the substrate edge have nearly identical etching rates. This is true, in particular, if the method for high-rate etching according to the present invention is combined with an aperture device in the plasma etching system as is known from German Patent 197 34 278. A very particularly advantageous variant of the method according to the present invention with regard to the uniformity of the etching over a wafer results if a plasma etching system as is known, for example, from German Patent 197 34 278 is further operated using a symmetrically fed plasma source as is proposed in German Application 199 00 179.

Moreover, the device for etching a substrate according to the present invention allows very high high-frequency powers of up to 5000 watts to be coupled into, in particular, inductive plasma sources in a stable manner. To this end, provision is advantageously made for a second means, in particular, for an automated impedance transformer which is controlled in a manner corresponding to the variation in the high-frequency power of the plasma source. Besides, the speed-adapted variation in power of the plasma source or of the high-frequency generator feeding the plasma source, respectively, is at the same time achieved in an advantageous manner via a ramp generator.

In this context, controlling the plasma power using a high-frequency generator and a ramp generator being in communication therewith as well as an impedance transformer for adapting the impedance, in particular, in a continuous and automated manner, is very advantageously suitable both for igniting and for adjusting upward a plasma up to highest power values and for alternating the power parameters at the plasma source between etching and deposition steps according to the

present invention.

The increased formation of etching species through a higher plasma power can further be promoted in an advantageous manner by increasing the flow of the fluor-delivering etching gas, for example, SF_6 simultaneously with the increase in power. In this case, to prevent sulfur depositions in the exhaust area of the etching system, the oxygen content is to be advantageously adjusted correspondingly. A further expedient way of increasing the production of fluor radicals concurrently with the power increase during the etching steps is increasing the process pressure. In this manner, fluor radicals are increasingly produced in the etching plasma in place of additional ions, thus increasing the ratio of the number of fluor radicals to the ion density. The exceeding of a certain ion density in the case of very high plasma powers is a disadvantage.

Besides, the power is advantageously not increased to, for example, more than 1500 watts during the deposition or polymerization steps. Since the deposition rate on the substrate suffices already when working with a relatively small power of 400 watts to 800 watts, an increase in power of the plasma source during the deposition steps combined with otherwise unchanged plasma etching parameters would, in any case, yield only few additional deposition species or would excessively compact the deposited polymer and lead to a carbon concentration in the polymer. Moreover, by maintaining the original small power of up to 1500 watts during the deposition process, it is, at the same time, advantageously avoided that the ion density and, consequently, the ion action upon the substrate are increased during the deposition steps. Because of this, the explained detrimental consequences of an increased ion density during the deposition steps do no occur.

Drawing

The present invention is explained in greater detail on the basis of the drawing and in the following description.

Figure 1 shows a plasma etching system having add-on parts;
Figure 2 shows a first RC circuit used in an analog ramp generator;
Figure 3 shows a second RC circuit having a diode; and
Figure 4 shows a third RC circuit having two diodes.

Exemplary embodiments

Figure 1 shows a plasma etching system 5 having a substrate 10, in particular, a patterned silicon wafer, which is to be provided with trenches in an anisotropic plasma etching method, and having a substrate electrode 11, a high-frequency a.c. voltage being applied, via a substrate voltage generator 12, to substrate electrode 11 and, via the substrate electrode, also to substrate 10. Moreover, provision is made for a plasma source 13 in the form of an inductive plasma source (ICP coil), known per se, which, together with an introduced reactive gas mixture, produces a plasma 14 in a reactor 15. To this end, a high-frequency electromagnetic alternating field is generated via a high-frequency generator 17, the reactive gas mixture being exposed to the electromagnetic alternating field. An arrangement of that kind is known, for example, from German Patent 197 34 278 C1. In Figure 1, moreover, provision is made for high-frequency generator 17 to be in communication with a component 18 incorporating a ramp generator 19, and for high-frequency generator 17 and plasma source 13 to be in communication via an impedance transformer 16 ("matchbox") known from the background art. The function and design of such a "matchbox" are known per se. A particularly advantageous embodiment of the "matchbox" in connection with an inductive plasma source having balanced coil power supply is described in unpublished

German Application 199 00 179.5.

Using plasma etching system 5, for example, an anisoptropic etching process including alternating etching and deposition steps is then carried out as is described, for example, in German Patent 197 34 278 C1 or, in particular, in German Patent 42 41 045 C1, the high-frequency power applied to plasma source 13 being changed periodically.

To this end, initially, high-frequency powers of 400 watts up a maximum of 1500 watts, preferably from 600 watts to 800 watts are applied to inductive plasma source 13 during the deposition steps. In the process, the process pressure lies between 5 mTorr to 100 mTorr, for example, at 20 mTorr.

The gas flow for the octafluorocyclobutane (C_4F_8) or hexafluoropropene (C_3F_6) used as passivating gas in the discussed example is 30 sccm to 200 sccm, preferably 100 sccm. The duration of a deposition step is 1 second to 1 minute, for example, 5 seconds.

During the etching steps following the deposition steps, high-frequency powers of 600 watts to 5000 watts, preferably of 3000 watts, are applied to inductive plasma source 13. In the process, the process pressure lies between 5 mTorr and 100 mTorr, for example, at 30 mTorr or 50 mTorr, and is preferably increased in comparison with the process pressure during the deposition steps. In the case of the etching gas SF_6 used in the discussed example, the used gas flows are 100 sccm to 500 sccm, preferably, 200 sccm to 300 sccm, oxygen being added to etching gas SF_6 in a proportion of 10 to 20 percent, preferably 15 % in a manner known per se to prevent sulfur depositions in the exhaust area of etching system 5.

During the etching steps, moreover, a high-frequency power of 1 watt to 50 watts is applied to substrate electrode 11 to accelerate ions generated in plasma 14 toward substrate 10. In

the discussed example, this high-frequency power is 8 watts in the case of a customary 6"-silicon wafer as substrate 10. According to the specific high-frequency power, moreover, an ion acceleration voltage of 1 V to 50 V, for example, of 15 V, is applied to substrate electrode 11. The duration of the etching step is approximately 3 seconds up to 2 minutes. In the discussed example, the duration is approximately 10 seconds.

The application of very high powers of up to 5000 watts to inductive plasma source 13 is technically very problematic since the plasma impedance changes in the measure in which the power is increased at plasma source 13. This is because an increasing electron and ion density is produced in plasma 14 as the plasma power, i.e., the excitation of plasma 14, increases. With the higher electron and ion density, however, plasma 14 increasingly has a lower impedance as seen from plasma source 13, i.e., the ideal state given in the case of high-density plasmas, the "short-circuit case", is more and more approached. This means at the same time that the adaptation conditions of inductive plasma source 13 to high-frequency generator 17, which usually has a fixed output impedance of mostly 50 Ω, change, namely dynamically with increasing power. Therefore, the output impedance of high-frequency generator 17 needs to be adapted to the impedance of inductive plasma source 13 which essentially depends on the produced charge carrier density in plasma 14.

In the discussed example, impedance transformer 16 ("matchbox") is provided for that purpose. This impedance transformer 16, usually by automatically and continuously or stepwise varying two variable capacitors which constitute a capacitive transformer (voltage divider), guarantees that plasma 14 or plasma source 13, respectively, are always optimally adapted, in terms of their impedance, to high-frequency generator 17 and its high-frequency power. If this

adaptation is not correct, reflected powers of up to 100 percent of the high-frequency power input occur which return into high-frequency generator 17, and there usually adjust back the forward power to prevent the generator output stage from being destructed. In the case of the plasma powers of up to 5000 watts used in the discussed example, this impedance adaptation is necessarily carried out dynamically.

Thus, for igniting plasma 14, the impedance transformer is initially brought into a so-called "preset" position which, up to a certain low plasma power, corresponds to the optimum "burning position" of impedance transformer 16, i.e., the position of impedance transformer 16 in the state "plasma on, low power". In this case, the automatic control of impedance transformer 16 must take over only a fine control to compensate for small tolerances of the plasma impedance. However, if the plasma power subsequently increases to values of, for example, more than 1000 watts, as used in the discussed example during the etching steps or while the plasma power is adjusted upward upon ignition, the plasma impedance changes significantly. Thus, for example, with 3000 watts high-frequency power coupled in at inductive plasma source 13, the adjustment of impedance transformer 16 is significantly different from the ignition position or the position with low plasma power.

The equivalent applies when the plasma power is switched from a lower to a markedly higher value during the transition from a deposition step to an etching step such as in the present example. The sudden power variation requires a corresponding correction at impedance transformer 16. If this correction is not carried out fast enough, the forward power on the generator side is abruptly reduced by corresponding protective circuits and, consequently, plasma 14 is temporarily extinguished or constantly blinks.

In a preferred embodiment of the present invention, the

explained difficulties during the ignition and adjusting upward of a plasma 14 in the case of plasma powers between 800 watts and 5000 watts as well as the periodic changeover of the plasma power, for example, between deposition steps and etching steps are solved in the discussed example in that the power of high-frequency generator 17 is increased "adiabatically", i.e., continuously or stepwise using a rate of rise which can be dynamically corrected by impedance transformer 16. In the discussed example, this means that the plasma power, for example, during the transition from a deposition step to an etching step, is increased in a slowed down manner while, at the same time, impedance transformer 16 continuously adapts to or corrects the changing impedance conditions on the basis of the changing plasma conditions.

In the concrete case of the plasma ignition, this manifests itself as follows: impedance transformer 16 is in the preselected ignition position and high-frequency generator 17 begins to adjust upward its power output continuously or stepwise in small steps from a preselected starting value to a target value. Plasma 14 will then ignite at a certain power, for example, 400 watts so that a defined impedance is present at plasma source 13. While high-frequency generator 17 then further increases its power output, more and more charge carriers are produced in plasma 14 and, consequently, the plasma or source impedance is changed. Impedance transformer 16 allows for these changes by ensuring the correct impedance transformation continuously and automatically, for example, in a manner known per se by adjusting variable capacitors. Thus, in the measure in which the generator power output increases, impedance transformer 16 automatically and as concurrently as possible adapts its adjustment at least temporarily to the resulting plasma conditions. In this manner, it is therefore also possible for plasma powers of several kilowatts, in particular, up to 5000 watts to be coupled into plasma 14 in a stable manner.

In the discussed example, typical values for the starting value lie at approximately 0 to 400 watts whereas the target value is usually 800 watts to 5000 watts. The time required for increasing the power between starting and target values typically lies at 0.2 sec to 5 sec, in particular, 0.5 sec to 2 sec.

In the discussed example, it is essential that, at least during power increases, no sudden changes in the power of high-frequency generator 17 occur which cannot be corrected by impedance transformer 16 but, if possible, all power changes be adapted to the correction rate of impedance transformer 16.

This also applies, in particular, to the alternation of the plasma power according to the present invention from a low value during the deposition steps to a very high value, preferably in the kilowatt range, during the etching steps. In this context, the deposition step with its relatively little power is initially uncritical. If now the change to the etching step takes place, the generator slowly adjusts upward its power output until, for example, after 2 seconds, the full generator power desired in the etching step is applied to plasma source 13. In the case of such a rate of rise, customary impedance transformers can easily correct the adjustment correspondingly.

During the change into the deposition step, the plasma power can be reduced to the lower power value, which is desired in the deposition steps, either suddenly or preferably also "adiabatically", i.e. in a slowed down manner and adapted to the correction rate of impedance transformer 16. Since the power during the deposition steps is uncritically low, however, both options are available here.

In the discussed example, the "adiabatic" control of the power of high-frequency generator 17 can be carried out either stepwise in small steps or continuously. To this end, for

example, in component 18, a digital ramp generator is programmed in a software-controlled manner which is known per se or an analog ramp generator 19, also known per se, is incorporated in component 18, thus being interconnected between the setpoint value output of a power control which, for example, is incorporated in component 18, and the setpoint value input of high-frequency generator 17.

Software control or the digital ramp generator are recommendable especially if the power of the high-frequency generator is requested using a digital command, for example, via a serial interface (RS232) as is the case with many known etching systems. In this case, the power of high-frequency generator 17 must be adjusted upward in small steps, starting from a starting value up to the desired target value, by a series of digital commands.

The analog variant via analog ramp generator 19 between the output of the system control and a generator setpoint value input is recommendable especially if high-frequency generator 17 is controlled using an analog signal, for example, a level value between 0 V and 10 V.

The simplest version of an analog ramp generator 19 is an RC circuit 23 shown in Figure 2, having a time constant which is adapted according to the desired rate of rise of the power of high-frequency generator 17. This first RC circuit has a delaying effect both in the upward and downward directions.

If the intention is for ramp generator 19 to be active only in the upward direction, i.e., only during power increase, but a desired decrease in the power of high-frequency generator 17 is intended to occur immediately, i.e. instantly, preferably, a second RC circuit 24 provided with a diode as is shown in Figure 3 is used.

If two freely selectable delay values are desirable for

adjusting upward and adjusting downward the power of high-frequency generator 17, preferably, a third RC circuit 25 provided with two different resistors and diodes allocated respectively as is shown in Figure 4 is used.

However, the exemplary circuits for ramp generators illustrated in Figures 2 through 4 are background art and are only intended to explain the design of the variants according to the present invention and to indicate to one skilled in the art how the desired ramp function can be derived therefrom. In Figures 2 through 4, in particular, the conducting-state voltage of approximately 0.6 Volts of the diodes is not taken into account.

In the discussed example, altogether, the typical duration of the increase in the high-frequency power during the change from a deposition step to an etching step lies at 0.2 to 5 sec, in particular, 0.5 sec to 3 sec. Compared to that, the duration of the decrease in the high-frequency power during the change from an etching step to a deposition or polymerization step is markedly shorter and lies between 0 sec to 2 sec, in particular 0 sec to 0.5 sec.

List of Reference Numerals

5	plasma etching system
10	substrate
11	substrate electrode
12	substrate voltage generator
13	plasma source
14	plasma
15	reactor
16	impedance transformer
17	high-frequency generator
18	component
19	ramp generator
23	first RC circuit
24	second RC circuit
25	third RC circuit

Patent Claims

1. A device for etching a substrate (10), in particular, a patterned silicon body with the assistance of a plasma (14), having a plasma source (13) for generating a high-frequency electromagnetic alternating field, it being possible for a high-frequency power to be applied to the plasma source with the assistance of a high-frequency generator (17), and having a reactor (15) for generating the plasma (14) from reactive particles through the action of the high-frequency electromagnetic alternating field upon a reactive gas or a reactive gas mixture, characterized in that provision is made for a first means producing a periodical change in the high-frequency power applied to the plasma source (13).

2. The device as recited in Claim 1, characterized in that the first means is a component for controlling the power of the high-frequency generator in which component a digital ramp generator is programmed via a software or in that the means is a component (18) for controlling the power of the high-frequency generator which component has an analog ramp generator (19).

3. The device as recited in Claim 2, characterized in that the analog ramp generator (19) has an RC circuit (23, 24, 25) which, in particular, is provided with at least one diode.

4. The device as recited in Claim 1, characterized in that provision is made for a second means which, during the periodical change in the high-frequency power applied to the plasma source (13), at least temporarily adapts the output impedance of the high-frequency generator (17) to the prevailing impedance of the plasma source (13) which changes as a function of the high-frequency power.

5. The device as recited in Claim 4, characterized in that the adaptation of the output impedance is carried out continuously or stepwise and that it is automated and in that the applied high-frequency power lies between 400 W and 5000 W.

6. The device as recited in Claim 4, characterized in that the second means is an impedance transformer (16).

7. A method for anisotropically etching a substrate (10) with a device as recited in at least one of the preceding Claims, the anisotropic etching process being carried out in separate etching and polymerization steps alternatingly following each other, and a polymer being applied to lateral patterns defined by an etching mask during the polymerization steps, the polymer being removed again in each case during the subsequent etching steps,
characterized in that, during the etching steps, at least temporarily, an in each case higher high-frequency power is applied to the plasma source (13) than during the deposition steps.

8. The method as recited in Claim 7, characterized in that, during the etching steps, at least temporarily, a high-frequency power of 800 watts to 5000 watts, in particular, of 2000 watts to 4000 watts is applied to the plasma source (13), and in that, during the deposition steps, at least temporarily, a high-frequency power of 400 watts to 1500 watts, in particular, of 500 to 1000 watts is applied to the plasma source.

9. The method as recited in Claim 7, characterized in that the increase in the high-frequency power during the change from the deposition steps to the

etching steps and/or the decrease in the high-frequency power during the change from the etching steps to the deposition steps are carried out stepwise or continuously.

10. The method as recited in Claim 9, characterized in that at least the increase in the high-frequency power is carried out in such a manner that during this time, at least temporarily, the impedance of the high-frequency generator (17) is adapted to the plasma impedance at least approximately in a an, in particular, continuous or stepwise and automated manner via the second means, in particular, via the impedance transformer (16).

11. The method as recited in Claim 9, characterized in that the duration of the increase in the high-frequency power during the change from a deposition step to an etching step is 0.2 sec to 5 sec, in particular, 0.5 sec to 3 sec and/or that the duration of the decrease in the high-frequency power during the change from an etching step to a deposition step is 0 sec to 2 sec, in particular, 0 sec to 0.5 sec.

12. A device for igniting a plasma (14) and for adjusting upward or pulsing a plasma power, having a plasma source (13), in particular, an inductive plasma source, for generating a high-frequency electromagnetic alternating field, it being possible for a high-frequency power to be applied to the plasma source with the assistance of a high-frequency generator (17), and having a reactor (15) for generating the plasma (14) from reactive particles through the action of the high-frequency electromagnetic alternating field upon a reactive gas or a reactive gas mixture,
characterized in that provision is made for a means which permits the adjustment of a continuous or stepwise

increase in the high-frequency power applied to the plasma source (13), starting from a starting value, to a target value.

13. The device as recited in Claim 12, characterized in that the means is a component for controlling the power of the high-frequency generator (17) in which component a digital ramp generator is programmed via a software or in that the means is a component (18) for controlling the power of the high-frequency generator (17) which component has an analog ramp generator (19).

14. The device as recited in Claim 12, characterized in that provision is made for an impedance transformer (16) which, during the increase in the high-frequency power, at least temporarily, adapts the output impedance of the high-frequency generator (17) to the prevailing impedance of the plasma source (13) in a an, in particular continuous or stepwise and automated manner, the impedance of the plasma source changing as a function of the high-frequency power.

15. A method for igniting a plasma (14) and for adjusting upward a plasma power with a device as recited in at least one of the Claims 12 through 14, characterized in that the continuous or stepwise increase in the high-frequency power from the starting value to the target value is accompanied by an at least temporary impedance adaptation of the high-frequency generator (17) to the prevailing plasma impedance via the second means, in particular, via the impedance transformer (16).

16. The method as recited in Claim 15, characterized in that the starting value is 0 to 400 watts and the target value is 800 watts to 5000 watts, and in that the increase of the starting value to the

target value is carried out over a period of 0.2 sec to 5 sec, in particular, 0.5 to 2 sec.

17. The method as recited in Claims 15 or 16, characterized in that the plasma (14) is ignited and adjusted upward in a time-pulsed manner.

Abstract

A device and a method capable of being carried out therewith for, preferably, anisotropically etching a substrate (10), in particular, a patterned silicon body, with the assistance of a plasma (14), is proposed. In the process, the plasma (14) is produced by a plasma source (13) to which a high-frequency generator (17) is connected for applying a high-frequency power. Moreover, this high-frequency generator is in communication with a first means which periodically changes the high-frequency power applied to the plasma source (13). Besides, provision is preferably made for a second means which adapts the output impedance of the high-frequency generator (17) to the prevailing impedance of the plasma source (13) which changes as a function of the high-frequency power. The proposed anisotropic etching method is carried out in separate and alternating etching and polymerization steps, a higher high-frequency power of up to 5000 watts being, at least temporarily, applied to the plasma source (13) during the etching steps than during the deposition steps. The proposed device is also suitable for igniting a plasma (14) and for adjusting upward or pulsing a plasma power from a starting value to up to 5000 watts.

Figure 1

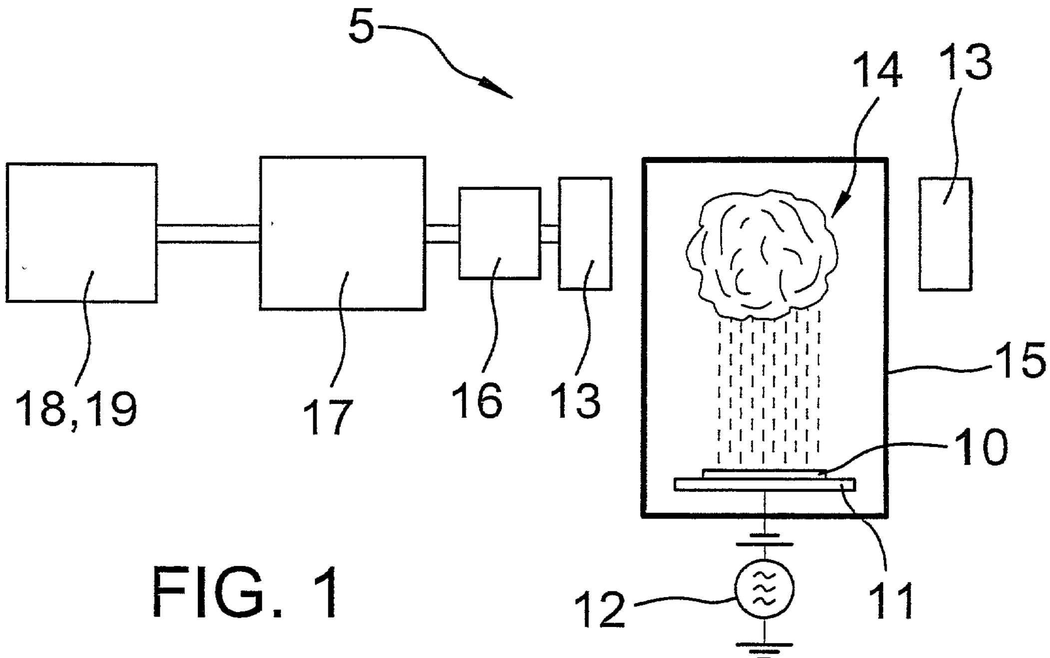

FIG. 1

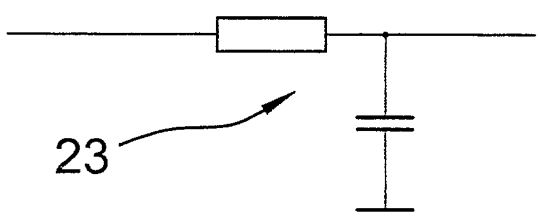

FIG. 2

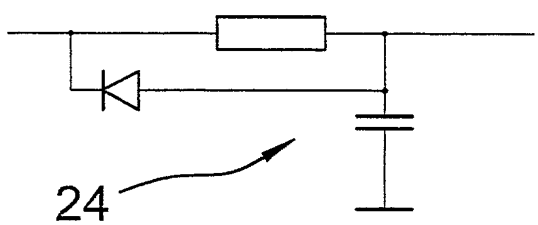

FIG. 3

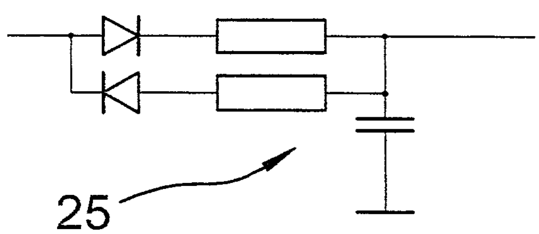

FIG. 4

DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am an original, first and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled **DEVICE AND METHOD FOR HIGH-RATE ETCHING A SUBSTRATE USING A PLASMA ETCHING SYSTEM AND DEVICE AND METHOD FOR IGNITING A PLASMA AND ADJUSTING UPWARD OR PULSING THE PLASMA POWER**, for which an application for Letters Patent was filed as PCT International Application Number **PCT/DE00/01906** on June 16, 2000, an English translation of the specification being filed herewith.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, § 1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code § 119 of any foreign application(s) for patent or inventor's certificate or of any PCT international applications(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed:

PRIOR FOREIGN APPLICATION(S)

Number	Country	Day/month/year filed	Priority Claimed Under 35 USC § 119
199 27 806.7	Germany	18 June 1999	Yes

EL302703929

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful and false statements may jeopardize the validity of the application or any patent issued thereon.